Announcements/Reminders

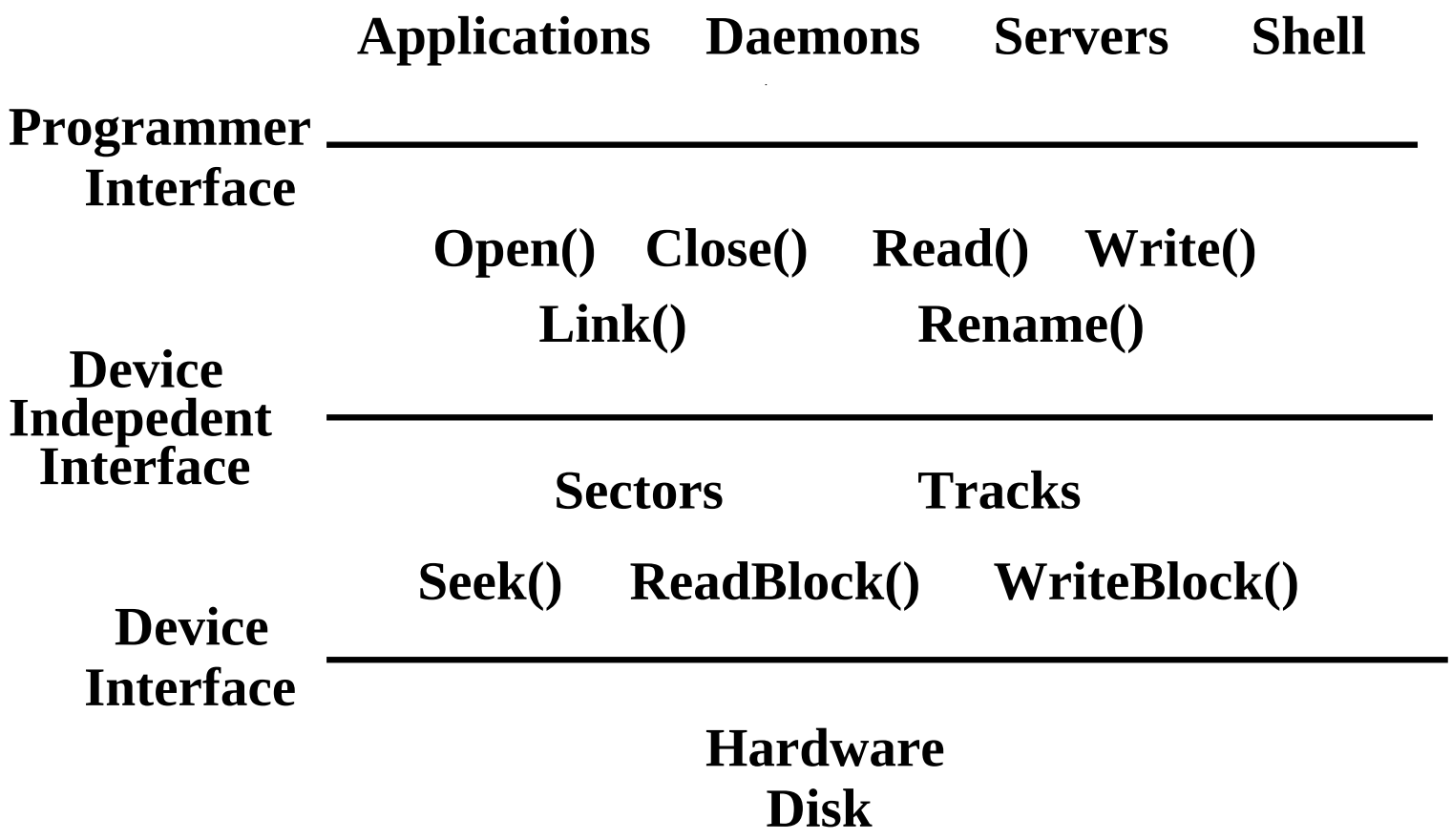
- Additional rmiregistry notes on the newsgroup

Today: File System Functionality

Remember the high-level view of the OS as a translator from the user abstraction to the hardware reality.

User Abstraction		Hardware Resource
Processes/Threads		CPU
Address Space	$\Longleftarrow$ **OS** $\Longrightarrow$	Memory
Files		Disk

File System Abstraction



User Requirements on Data

- **Persistence:** data stays around between jobs, power cycles, crashes
- **Speed:** can get to data quickly
- **Size:** can store lots of data
- **Sharing/Protection:** users can share data where appropriate or keep it private when appropriate
- **Ease of Use:** user can easily find, examine, modify, etc. data

Hardware/OS Features

- Hardware provides:
  - **Persistence:** Disks provide non-volatile memory
  - **Speed:** Speed gained through random access
  - **Size:** Disks keep getting bigger (typical disk on a PC=20-100GB)
- OS provides:
  - **Persistence:** redundancy allows recovery from some additional failures
  - **Sharing/Protection:** Unix provides read, write, execute privileges for files
  - **Ease of Use**
    - Associating names with chunks of data (files)
    - Organize large collections of files into directories
    - Transparent mapping of the user's concept of files and directories onto locations on disks

Files

- **File:** Logical unit of storage on a storage device
  - Formally, named collection of related information recorded on secondary storage
  - **Examples:** reader.cc, a.out
- Files can contain programs (source, binary) or data
- Files can be structured or unstructured
  - Unix implements files as a series of bytes (unstructured)
  - IBM mainframes implements files as a series of records or objects (structured)
- File attributes: name, type, location, size, protection, creation time

User Interface to the File System

Common file operations:

Data operations:

- Create()
- Delete()
- Open()
- Close()
- Read()
- Write()
- Seek()

Naming operations:

- HardLink()
- SoftLink()
- Rename()

Attributes (owner, protection,...):

- SetAttribute()
- GetAttribute()

OS File Data Structures

1. Open file table - shared by all processes with an open file.
   - open count
   - file attributes, including ownership, protection information, access times, ...
   - location(s) of file on disk
   - pointers to location(s) of file in memory
2. Per-process file table - for each file,
   - pointer to entry in the open file table
   - current position in file (offset)
   - mode in which the process will access the file (r, w, rw)
   - pointers to file buffer

File Operations: Creating a File

- **Create(name)**
  - Allocate disk space (check disk quotas, permissions, etc.)
  - Create a file descriptor for the file including name, location on disk, and all file attributes.
  - Add the file descriptor to the directory that contains the file.
  - Optional file attribute: file type (Word file, executable, etc.)
    - **Advantages:** better error detection, specialized default operations (double-clicking on a file knows what application to start), enables storage layout optimizations
    - **Disadvantages:** makes the file system and OS more complicated, less flexible for user.
    - Unix opts for simplicity (no file types), Macintosh/Windows opt for user-friendliness

File Operations: Deleting a File

- **Delete(name)**
  - Find the directory containing the file.
  - Free the disk blocks used by the file.
  - Remove the file descriptor from the directory.

File Operation: Opening Files

- **fileId = Open(name, mode)**
  - Check if the file is already open by another process. If not:
    - Find the file.
    - Copy the file descriptor into the system-wide open file table.
  - Check the protection of the file against the requested mode. If not ok, abort
  - Increment the open count.
  - Create an entry in the process's file table pointing to the entry in the system-wide file table. Initialize the current file pointer to the start of the file.

File Operations: Closing Files

- **Close(fileId)**
  - Remove the entry for the file in the process's file table.
  - Decrement the open count in the system-wide file table.
  - If the open count == 0, remove the entry in the system-wide file table.

OS File Operations: Reading a File

- **Read(fileID, size, bufAddress)** - sequential access (tape model)
  - OS reads "size" bytes from current file position, fp, into "bufAddress" and increments current file position by size

```
for (i = 0; i < size; i++)
     bufAddress[i] = file[fp + i];
fp += size;
```

- **Read(fileID, from, size, bufAddress)** - random access (disk model)
  - OS reads "size" bytes from file position "from" into "bufAddress"

```
for (i = from; i < from + size; i++)
     bufAddress[i - from] = file[i];
```

OS File Operations

- **Write** is similar to reads, but copies from the buffer to the file.
- **Seek** just updates fp.
- **Memory mapping** a file
  - Map a part of the portion virtual address space to a file
  - Read/write to that portion of memory ⇒OS reads/writes from corresponding location in the file
  - File accesses are greatly simplified (no read/write call are necessary)

File Access Methods

- Common file access patterns from the programmer's perspective
  - **Sequential:** data processed in order, a byte or record at a time.
    - Most programs use this method
    - *Example:* compiler reading a source file.
  - **Keyed:** address a block based on a key value.
    - *Example:* database search, hash table, dictionary

- Common file access patterns from the OS perspective:
  - **Sequential:** keep a pointer to the next byte in the file. Update the pointer on each read/write.
  - **Random:** address any block in the file directly given its offset within the file.

Naming and Directories

- Need a method of getting back to files that are left on disk.
- OS uses numbers for each file
- Users prefer textual names to refer to files.
  - **Directory:** OS data structure to map names to file descriptors

Naming and Directories

- Naming strategies
  - **Single-Level Directory:** One name space for the entire disk, every name is unique.
    1. Use a special area of disk to hold the directory.
    2. Directory contains <name, index> pairs.
    3. If one user uses a name, no one else can.
    4. Some early computers used this strategy. Early personal computers also used this strategy because their disks were very small.
  - **Two Level Directory:** each user has a separate directory, but all of each user's files must still have unique names

Naming Strategies (cont)

- Multilevel Directories - tree structured name space (Unix, and all other modern operating systems).
  1. Store directories on disk, just like files except the file descriptor for directories has a special flag (indicating file or directory).
  2. User programs read directories just like any other file, but only special system calls can write directories.
  3. Each directory contains <name, fileDesc> pairs in no particular order. The file referred to by a name may be another directory.
  4. There is one special root directory. *Example:* How do we look up name: /usr/local/bin/netscape

Referential naming (hard links)

- Hard links (Unix: *ln* command)
  - A hard link adds a second connection to a file
  - *Example:* creating a hard link from B to A

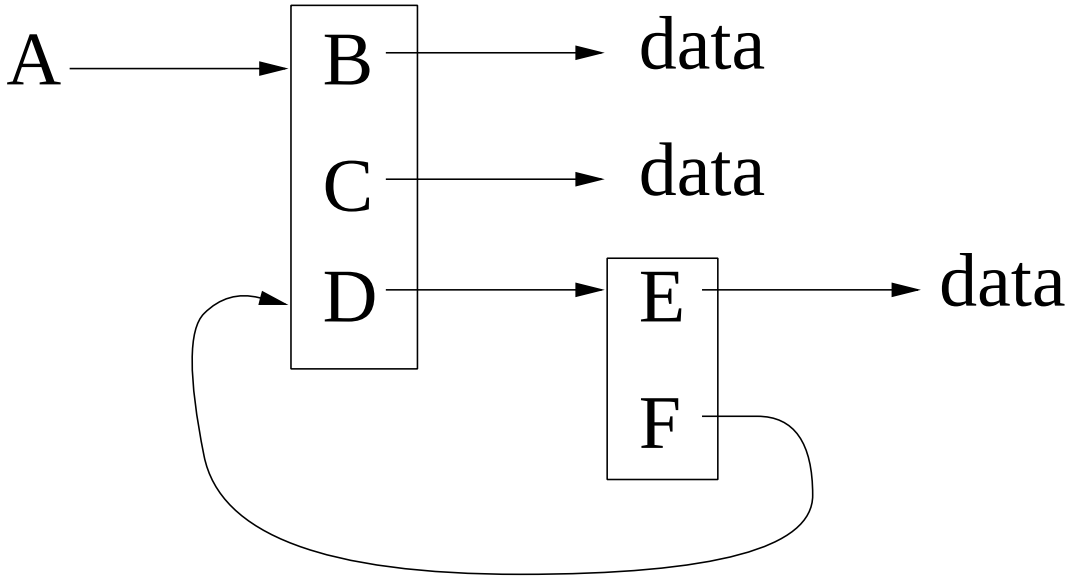
Initially:	A → file #100
After "ln A B":	A → file #100
	B → file #100

  - OS maintains reference counts, so it will only delete a file after the last link to it has been deleted.

Referential naming (hard links)

- *Problem:* user can create circular links with directories and then the OS can never delete the disk space.

- *Solution:* No hard links to directories



Referential Naming

- Soft links (Unix: *ln -s* command)
  - A soft link only makes a symbolic pointer from one file to another.
  - *Example:* creating a soft link from B to A

Initially:	A $\rightarrow$ file #100
After "ln A B":	A $\rightarrow$ file #100
	B $\rightarrow$ A

  - removing B does not affect A
  - removing A leaves the name B in the directory, but its contents no longer exists
  - *Problem:* circular links can cause infinite loops (e.g., trying to list all the files in a directory and its subdirectories)
  - *Solution:* limit number of links traversed.

Directory Operations

- Search for a file: locate an entry for a file
- Create a file: add a directory listing
- Delete a file: remove directory listing
- List a directory: list all files (*ls* command in UNIX)
- Rename a file
- Traverse the file system

Protection

- The OS must allow users to control sharing of their files ⇒control access to files
- Grant or deny access to file operations depending on protection information
- **Access control bits** (UNIX)
  - Three categories of users (owner, group, world)
  - Three types of access privileges (read, write, execute)
  - Maintain a bit for each combination (111101000 = rwxr-x—)
- **Access lists and groups** (Windows NT, Andrew File System)
  - Keep an access list for each file with user name and type of access
  - Lists can become large and tedious to maintain

Summary of File System Functionality

- Naming
- Protection
- Persistence
- Fast access

Next Time

- Friday: come with questions about HW 3
- Monday: File System Implementation Issues (Chapter 11)